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Redesigning Public Street Lighting Using Photometric Method

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ABSTRACT

Street lighting with LED (Light-Emitting Diode) technology is currently the main option of public lighting in almost every country. Even though LED technology is a less costly selection, there needs to be well planned in an attempt to acquire high efficiency. The photometric approach was tested in this study in order to redesign the existing approach used in street lighting in Indonesia. The redesigning process was carried out using software namely DIALux on two different schemes: one with homogeneous luminaire and the other one with the non-homogeneous luminaire. The results of this study showed that the most significant factors in redesigning street lighting covered types of the lamp, pole distance, pole height, and proper lighting angles which could affect the illumination value on both the main road and the sidewalks. In addition, it has also been proven that a homogeneous approach using LED lamp lighting promoted uniformity as well as optimum illumination.

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1. INTRODUCTION

Public street lighting (PSL) comprises lamps used to give clear sight for pedestrians and drivers at night aiming for enhancing traffic safety from crimes (Welsh & Farrington, 2008). For the last 100 years, there has been the development of lamp technology starting from carbon filament, high voltage sodium, to what is frequently used currently called light-emitting diode (LED) (Johnson, 2002). It is proven that the LED system has been globally adopted since the 20th century (Kadirova & Kajtsanov, 2017). Nowadays, one of the most advanced innovations in LED technology is its lumination which is equal to the other lamps, but with significantly lower power consumption (Dracker & De Laquil III, 1996). LED does not only show lower power consumption but also enhances the lumination quality (Cook, 2000). If compared to the previously implemented street lighting, LED technology has a smaller size, longer time span, brighter lumination, lower maintenance cost, less technical problems (Cheng et al., 2013), higher energy efficiency (Chen et al., 2008), and is mercury-free and environmentally-friendly (Long et al., 2009). In street lighting, one of the most frequently discussed issues is energy efficiency (Reinhard & Andreas, 2011).

It is revealed that efficiency in street lighting installment is an interesting topic to be studied for the last few years (Rabaza et al., 2016). Some of the studies have proven that development on energy efficiency decreases the power consumption in street lighting even up to 50%. Therefore, designers have an important role in finding the optimal solutions to such issues related to decreasing the electricity cost, increasing the safety of pedestrians and drivers, reducing light pollution, and supporting sustainable development (Gómez-Lorente et al., 2013). Studies on energy efficiency for street lighting installment are divided into three parts: first, those are focusing on the development of the technology of lamps and their lumination; second, those are focusing on optimizing the design of street lighting system whose main purpose is to identify the best combination of the design parameter maximizing the lumination uniformity and efficiency; and third, those are focusing on the development of lamp control system for energy consumption reduction (Gómez-Lorente et al., 2013).

There are various methods to solve issues related to energy efficiency in street lighting. One of which is namely mesopic and photometry method (Carli et al., 2013), which has been scientifically proven to be able to cope with the issue (Lin et al., 2006). Another method is the multi-objective evolutionary algorithm (MOEA) method which has been widely used in various fields, such as energy engineering (Ylinen et al., 2011), mechanical structure (Alonso et al., 2012), and machines (Mezzomo et al., 2010). In the context of street lighting, the MOEA method is applied for an installation with similar distance and constant road width (Abbasgholipour et al., 2011), and it shows good results in dealing with the energy efficiency of the street lighting (Sędziwy, 2016).

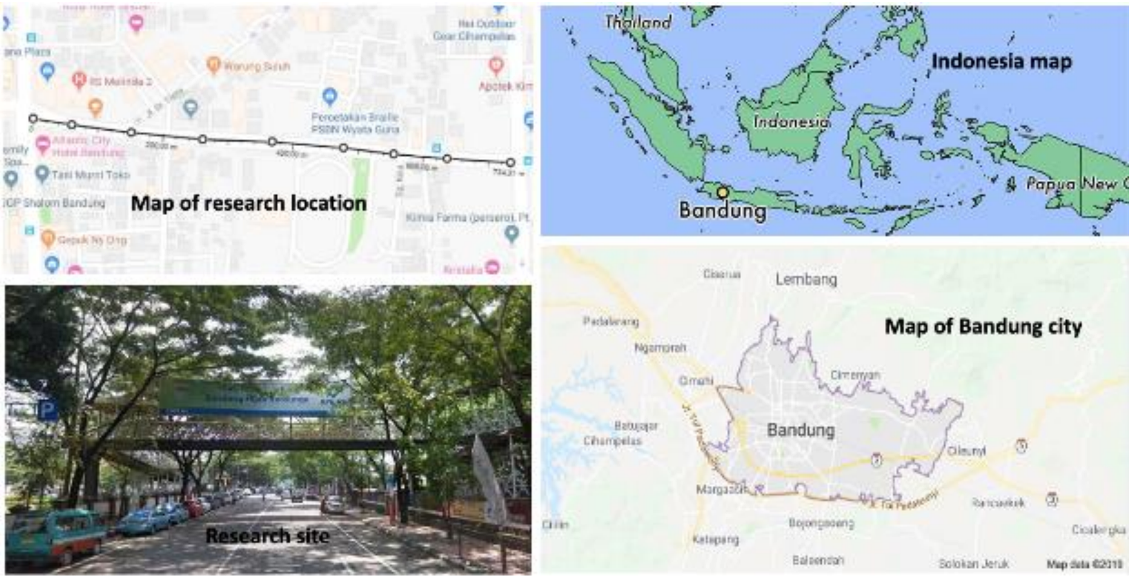

Figure 1. Location of research site

In this study, we intended to redesign public street lighting by comparing its energy efficiency based on two different approaches, namely homogeneous luminaire approach and non-homogeneous luminaire approach. We believe that the comparison of both approaches is the research gap to be filled since there is a very limited number of previous studies comparing both approaches. The method employed in this study is mesopic photometric calculation. The mesopic photometric calculation is a formulation of mesopic vision which highlights the combination of photopic vision and scotopic vision in low but not quite dark lighting situations.

2. RESEARCH METHODOLOGY

This study was initiated by a survey on the research site located on a road in the city of Bandung, Indonesia (**Figure 1**). The length of the road is 734.31 m, and its width is 14 m. The width of each right and left sidewalk is 3 m and there are their lanes within the road. There were 16 items of PSL installed using high-pressure sodium (HPS) lamps type SON-T 250 W E E40 SL/12 whose height was 7.68 m. All of the lamps were installed well. The complete procedure of the research is shown in **Figure 2**.

The information on the road was acquired in real-time with the help of the Google Map application. The calculation of the number of PSLs on each road was done in daylight. Surveyors recorded it while walking through the road. In the meantime, the survey on whether the lamps turn on normally was done in the night time starting from 8 to 11 PM Indonesian time. The calculation of the average distance among poles was conducted by dividing the length of the road by the number of the PSL on the road. The lumination quality was measured based on the lumination method, using a tool namely lux meter. The measurement took place on the ground/ road level with a maximum elevation angle of 45 degrees. It was also measured using a random sampling technique covering the following criteria: public places, signage placement, bend in the road, tunnels, flyovers, and parking areas. In order to identify the feasibility of PSL lumination, this study compared it with the normal lumination standard version SNI 7391:2008 (Indonesian National Standards) which was the main reference of lumination standards in Indonesia.

The measurement of illumination was conducted using handheld lux meter LX-113S. In this context, illumination is the core measurement of lighting intensity reflected by the source of lighting (public street lighting) per candle (cd). The tool specification consisted of the display of an LCD with the size of 44 mm x 29 m; a sensor using photodiode filter, color correction, and spectrum in accordance with the standards of the International Commission on Illumination (Commission Internationale de l’Eclariage/CIE). The measurement ability on the automatic range was able to be carried out in either lux (lx) or feet-candle (ft-cd). In which lx is the SI unit of luminous emittance and illuminance which measures flux per area of the unit, while ft-cd is either US customary or British Imperial unit of the emittance. In other words, one foot-candle can be defined as a one-candela source illuminating a surface as far as one foot away from the source of light. The complete measurement ability is described in **Table 1**.

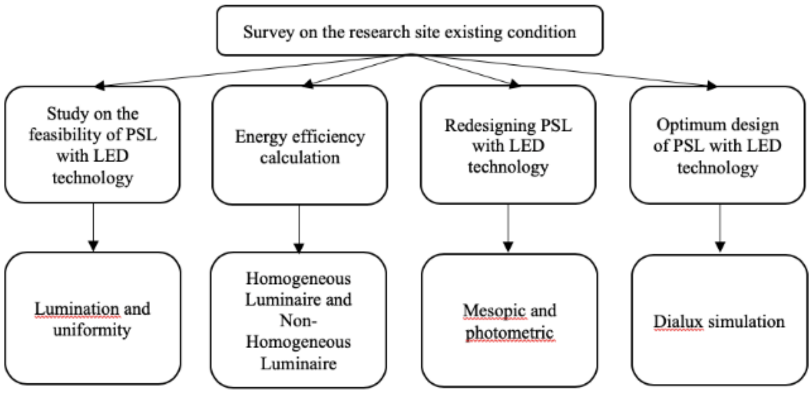

Figure 2. Research procedure.

Table 1. Specification of the lux meter (LX-113S).

Range (lx)	Range displayed (lx)	Resolution (lx)	Accuracy
2.000	0-1.999	1	± (5% + 4 lx)
20,000	2.000-19,990	10	± (5% + 40 lx)
50,000	20,000-50,000	100	± (5% + 400 lx)
Range (ft-cd)	Range displayed (ft-cd)	Resolution (lx)	Accuracy
200	0-199.9	0.1	± (5% + 0.4 ft-cd)
2.000	200-1.999	1	± (5% + 4 ft-cd)
5.000	2.000-5.000	10	± (5% + 40 ft-cd)

In order to measure the distance among poles, road width, sidewalk width, road length, and pole height, we used a digital laser meter, BOSCH DLE 70 3 601 K16 670, due to its easy use and accurate results in comparison with using manual meters. The tools were also equipped with diode laser components that could capture the length of lightwave up to 635 nm, with energy less than 1 mW. This type of laser was categorized into the second grade as a meter and could measure the distance ranging from 0.05 to 70.00 m. Ratio uniformity was measured to acquire information on the cost comparison between illumination and lumination of a certain road. One of the methods administered in this study, homogeneous luminaire, was the method used to design PSL by neglecting the real condition and assuming that the lumination, roads, and pedestrians' conditions were homogeneous. On the other hand, the other method, namely non-homogeneous luminaire, was the method considering the real condition of such factors of the roads as road profile and lamp specification data. Additionally, a simulation method was selected to redesign the PSL.

The next step was arranging the research instruments such as information on the road profile and lamp and meter specification. Subsequently, the process was to determine the profile data of the roads which would be studied. The profile data were then processed in a DIALux software to input data such as the conditions of the road, the road width, the width of the road median, the number of lanes, the bicycle lane, the pedestrian lane, and factors of lumination reduction. The data collection took place from 9 to 12 PM since it was the most ideal condition of collecting the data due to the minimum number of activities. The DIALux software combined all of the information data and parameters to be designed in accordance with CIE. After that, design on DIALux was carried out by selecting types of lamps used, types of PSL pole placement, PSL pole height, PSL pole distance, and the distance of lamp spot center to the road edges.

The measurement of lamp intensity was conducted using the illumination method by placing a lux meter one meter above the ground level on the elevation angle at 45 below the PLS poles. There were three points of the measurement including the point directly under the lamps, the point among each lamp, and the last one across the road. The total amount of the distance of each spot was then summed up and divided to find out its average. The illustration of the PSL il-lumination is presented in **Figure 3**. The lamp height from the road level when this study was taking place was 7.68 m and the average distance among the poles was 45.802 m.

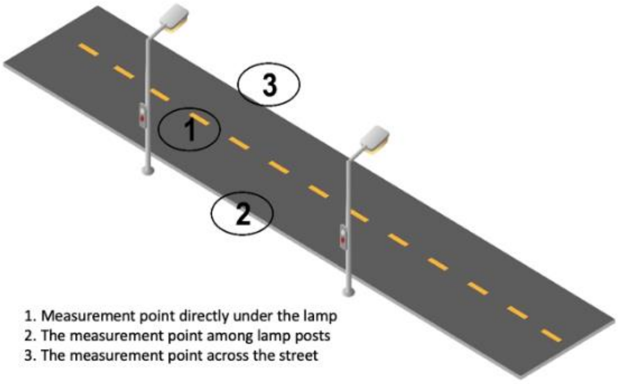

Figure 3. PSL illumination measurement on three points.

Table 2. Results of PSL illumination measurement on research site.

Pole Number	Distance to the next pole (m)	Average score among poles (m)	Lamp measurement data (lux)			Illumination average (lx)	Total of illumina-tion average (lx)	Uniformity ratio
			Under the lamp	Across the street	Among lamps			
1	46.284		24	7	1	10.7		
2	39.132		43	1	1	15.0		
3	66.463		48	2	1	17.0		
4	38.017		18	3	2	7.7		
5	40.531		9	2	3	4.7		
6	39.814		6	2	2	3.3		
7	43.365		15	2	2	6.3		
8	34.754	45.802	40	4	2	15.3	8.94	0.37
9	78.943		10	2	3	5.0		
10	39.560		19	2	1	7.3		
11	38.026		18	4	1	7.7		
12	38.060		19	1	1	7.0		
13	85.425		16	4	2	7.3		
14	53.301		39	4	2	15.0		
15	43.410		6	4	3	4.3		

The measurement of lumination intensity of all the poles had been carried out three times to eventually result in its average. To find out the uniformity, we divided the minimum illumination by the average illumination. The acquired average value of all the poles was 8.94 lx and its uniformity was 0.37 lx. Referring to the standards of SNI, the illumination and uniformity values were above the standards, which ranged from 3 to 7 lx. Illumination value that is too high will cause dazzled light and is dangerous to both pedestrians and drivers. Based on the data analysis, it was found that not every lamp has equal lumination. They vary from each other as there are such distracting factors as age of the lamps, the billboard position, the tree position, etc. The complete results of the illumination are described in **Table 2**.

Table 3 shows the results of the PSL pole measurement, in which the average pole height was 7.68 m. In addition to measuring the height, angle, length of the polearms, the length of the slope was also calculated to complete the data necessary. The illustration of the PSL pole measurement can be viewed in **Figure 4**.

Table 3. Specification of PSL poles on the research site.

Pole number	Angle of the pole	Pole height	Length of the pole	Length of slope
1	48.1	5.706	5.120	7.667
2	58.1	6.819	4.244	8.033
3	60.9	7.329	4.339	8.239
4	60.3	7.234	4.126	8.329
5	63.8	8.484	4.174	9.456
6	60.0	7.336	4.235	8.482
7	59.0	7.530	4.524	8.785
8	59.8	7.202	4.192	8.334
9	65.6	9.071	4.114	9.961
10	58.9	7.476	4.509	8.731
11	62.3	8.042	4.222	9.084
12	63.6	8.503	4.221	9.494
13	73.4	6.708	1.999	7.000
14	62.1	8.435	4.466	9545
15	66.4	8.795	3.842	9.598
16	76.7	8.195	1.937	8.421
Total	999	122.865	64.264	139.159
Average	**62.44**	**7.68**	**4.017**	**8.697**

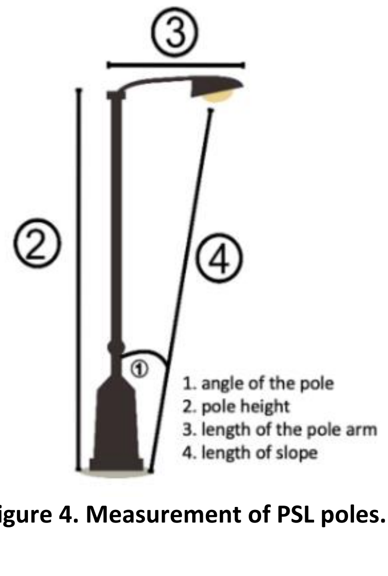

Figure 4. Measurement of PSL poles.

Table 4. Scheme of the PSL redesign.

	Scheme 1	Scheme 2		
		Design 1	Design 2	Design 3
Type of Lamps	***Light Emitting Diode* (LED)**	***Light Emitting Diode* (LED)**	***Light Emitting Diode* (LED)**	***Light Emitting Diode* (LED)**
Manufacturer	Gewiss	Nikkon	Unilamp	Simes
Type	GWS7827	S433-MP ARGENTO K09121	7297-1-4-862-XX	S.7140N + S.2816
Efficiency	92 lm/W	142 lm/W	143 lm/W	89 lm/W
Lumination flux	10,072 lm	13,500 lm	11,580 lm	7,480 lm
Nominal voltage	220-240 VAC, 50/60 Hz	220-240 VAC, 50/60Hz	220-240 VAC, 50/60Hz	220-240 VAC, 50/60Hz
Electrical power	110 W	85 W	85 W	85 W
Colour rendering index (CRI)	70	70	70	70
Distance of the poles to the road	3 m	3 m	3 m	3 m
Minimum illumination criteria	5 lx	5 lx	5 lx	5 lx
Lumination uniformity	0.14	0.14	0.14	0.14
Types of poles	Single row	Single row	Single row	Single row
Distance among the poles	45.802 m	58 m	24 m	54 m

As described in **Table 3** that some of the poles do not have an equal height to the others. This was due to the fact that some of the lamps were installed on not lam-dedicated poles but instead installed on poles used for communication and electricity poles such as ones for telecommunication and electricity. Some other unequally sized poles did not follow the standardized height either. According to the SNI, the assigned lamps for PSL were type SON 250 W with a height of 10 m. This means that the PSL poles on the research site did not meet the national standards.

The redesign of PSL in this study used DIALux Evo 8.0 software. On the research site, it was found that the lamps used are type SON-T 250 W E E40 SL/12 with a specification of 250 W, 25,200 lm, and estimated lifetime as long as 30,000 h. This type of lamp is classified as an energy-consuming kind. This is one of the fundamental reasons for the need to redesign the PSL into a more energy-efficient type of lamp. There were two schemes of redesign in this study. The first scheme involved replacing the lamps on the research site with LED lamps without changing the real condition of the site. However, the pole height and its arm's length were adjusted to the database generated by DIALux software. This scheme was named a non-homogeneous luminaire. The second scheme, on the other hand, compared the PSL redesign by replacing the lamps on the research site using three different LED lamp brands with the same power. The PSL positioning in the second scheme was in accordance with that stated in the national standards. This scheme was named homogeneous luminaire. Thus, the second scheme did not only replace the existing lamps but also changed the distance between the poles and the pole height based on SNI 7391:2008. The data on both schemes are presented in **Table 4**.

3. RESULTS AND DISCUSSION

This study reported the results of planning the PSL with two schemes, namely homogeneous luminaire and non-homogeneous luminaire using a mesopic photometric approach. It is known that mesopic vision is a combination of scotopic vision and photopic vision in a low lighting condition (but not dark) with the level of lighting at 0.001 to 3 cd/m^2 (Rabaza et al., 2013) (Stockman & Sharpe, 2006). The design is considered proper to be implemented in the PSL. The simple measurement is obtained by calculating the amount of light in a certain spot using a lux meter tool.

In the meantime, the non-homogeneous luminaire scheme is administered by redesigning the PSL without changing the distance among the poles (based on the real condition), but by replacing the previous lamp type SON-T 250 W E E40 SL/12 with an LED lamp type Gewiss GWS7827. The lamp is operated under 220–240 V at the frequency of 50/60 Hz. The power consumption is about 110 W and the flux lumination created is as high as 10,072 lm, with an efficiency of 92 lm/W, and color rendering index (CRI) as much as 70 to 100. CRI is defined as the ability of light to shine on an object with the result equal to one under the sun. In addition, the distance from the poles to the street is based on the existing condition, which is 3 m. Based on the Indonesian lighting standard (SNI 7391-2008), the illumination level of the primary collector road ranges from 3 to 7 lx with the uniformity of light at 0.14. To have that illumination level with the aforementioned standard, the average illumination score is as much as 5 lx. This is due to the fact that there is a decrease in lamp performance so that the illumination level will stick to the standard. The type of poles used is single row and the distance among the poles is based on the existing condition, which is 45.802 m.

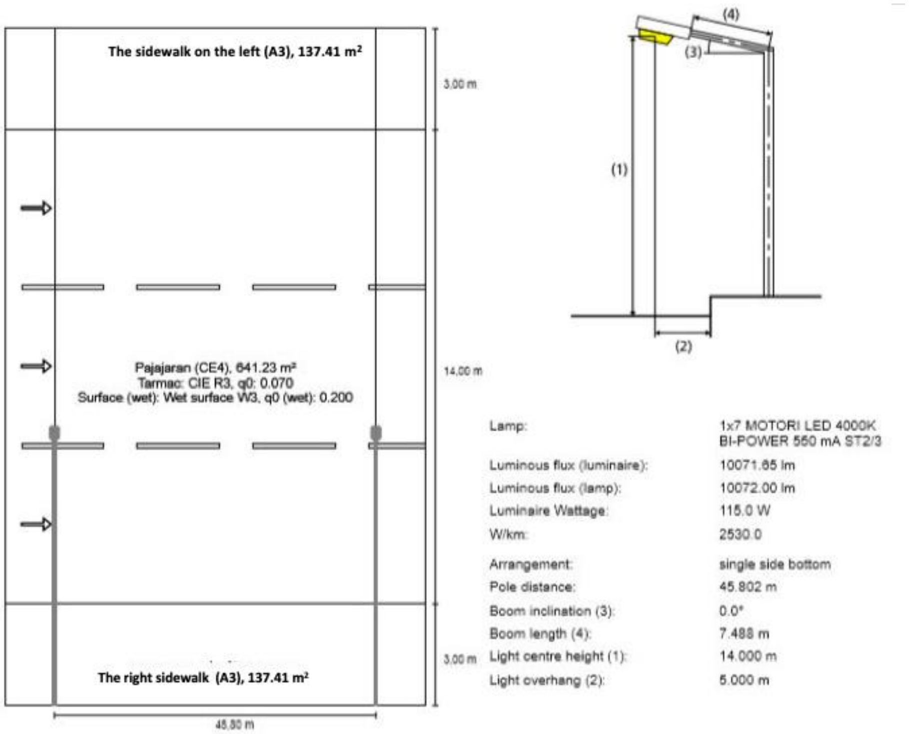

Figure 5. Example of PSL design input for scheme 1.

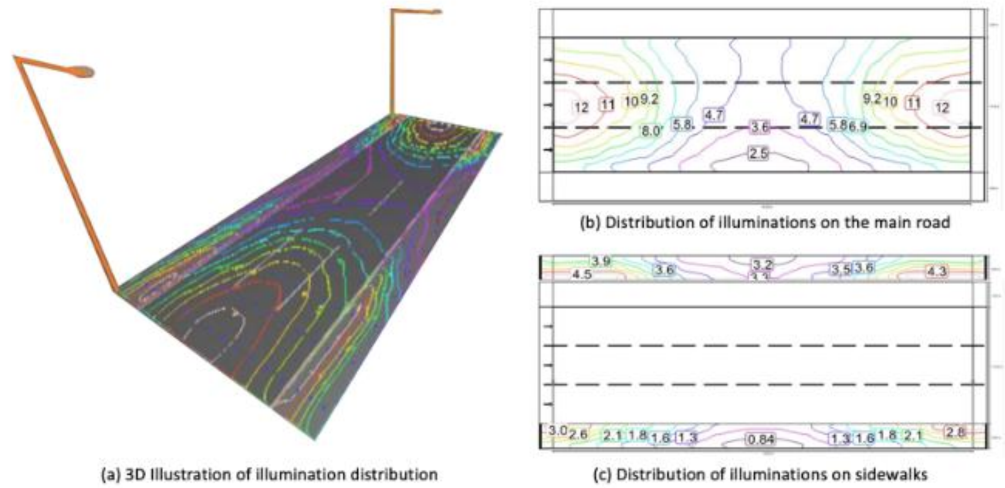

Figure 6. Simulation results of scheme 1.

A simulation using software namely DIALux requires data such as pole distance, light center height, light overhang, and pole distance from the roadway. After everything is complete, the software will automatically calculate and give a recommendation of proper illumination as shown in **Figure 5**. The lumination flux obtained was 10,072 lm and the power per lamp was 110 W. The calculation shows that the average illumination on the left sidewalk was 3.75 lx with a uniformity of 0.83 and that of the right sidewalk was 1.74 lx with a uniformity of 0.41. The average illumination spot on the roadway was 7.18 lx with a uniformity of 0.27. In this scheme, the distance among poles is 45.802 m, the pole height is 14 m, the distance of the center light to the side of the road was 5 m, and the distance of the poles to the roadway was 3 m.

Figure 6 shows the simulation results of Scheme 1. Meanwhile, **Figure 6(a)** shows the 3D illustration of the PSL lighting uniformity on all the areas of the road (main road and sidewalk). The color difference reflected in the figure shows the different illumination distributions. The higher the illumination value on the road, the better the lighting uniformity will be.

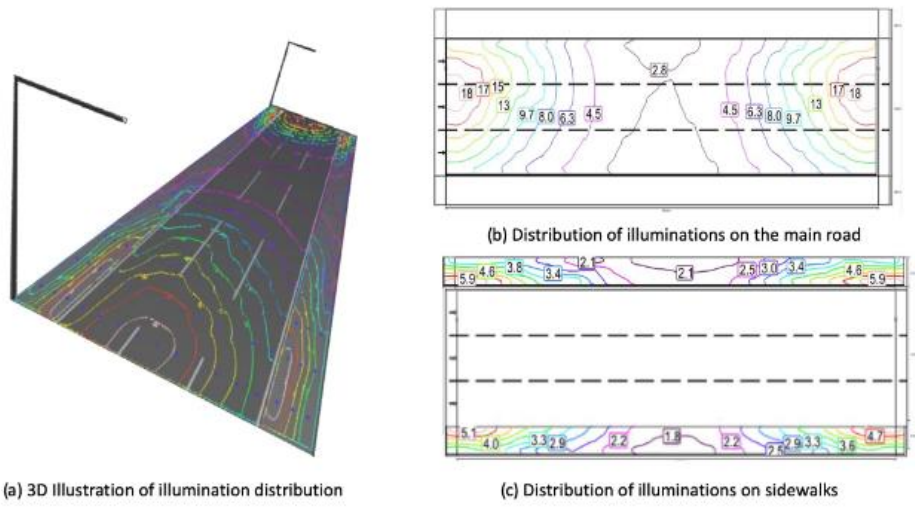

Figure 7. Simulation results of scheme 2 (design 1)

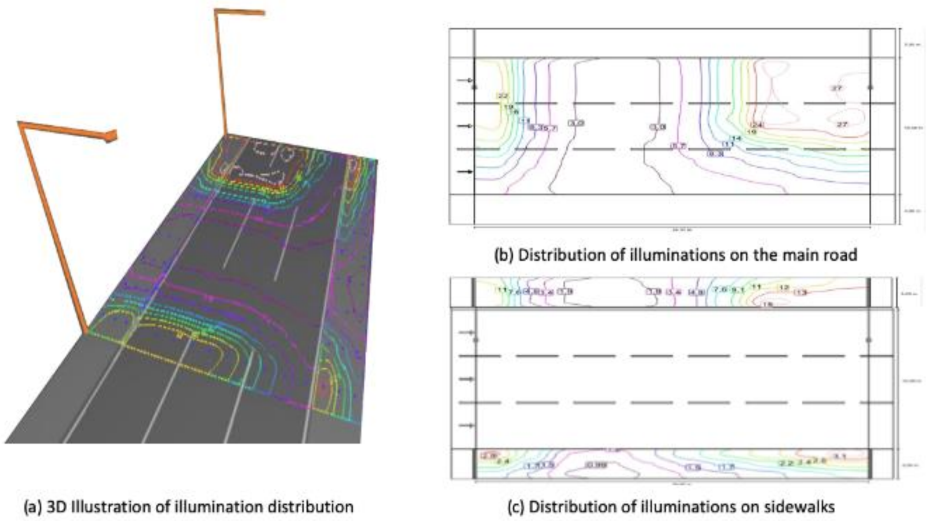

Figure 8. Simulation results of scheme 2 (design 2)

In the meantime, **Figures 6(b)** and **6(c)** consecutively show the illumination uniformity on the main road and both right and left sidewalks. In this Scheme 1, there are 160 luminary spots on the main road, with illumination values ranging from 1.92 to 13.00 lx, illumination average of 7.18 lx, and uniformity of 0.27. On the left sidewalk, there were 48 luminary spots with average illumination of 3.13 lx and uniformity of 0.83. Whereas, on the right sidewalk, there were 48 luminary spots with an average illumination of 1.74 lx and a uniformity of 0.41.

Figures 7, **8**, and **9** in a row show the design results of Scheme 2. This scheme attempts to optimize the values of the PSL lumination with equal power, which was 85 W with different lamp brands. All the lamps were able to operate between 220 and 240 V AC at the frequency of 50/60 Hz. Table 5 shows the simulation results using DIALux software. It had been proven that all the designs met the national standards of Indonesian PSL. The illumination average value of Design 1 resulted in 200 luminary spots and that of Design 2 resulted in 100 luminary spots. Meanwhile, that of Design 3 resulted in 180 luminary spots.

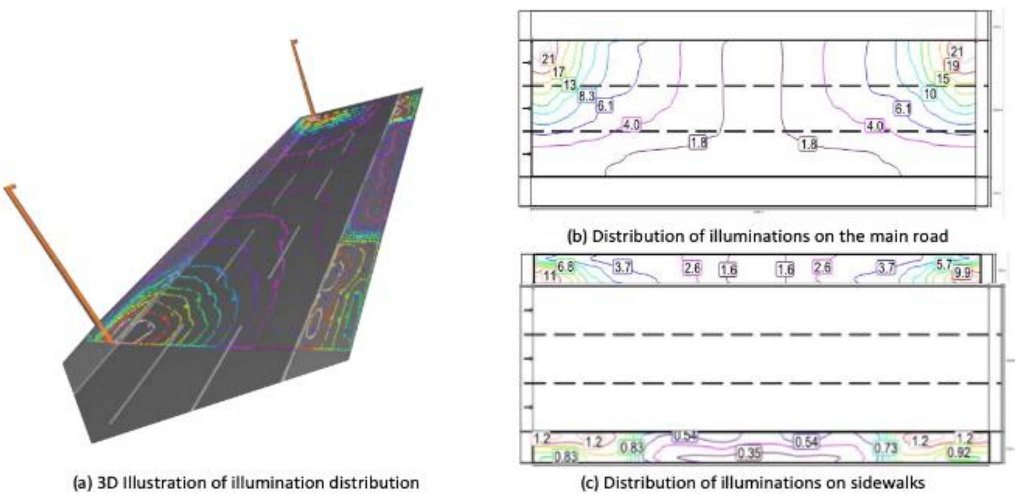

Figure 9. Simulation results of scheme 2 (design 3)

The trial of the Scheme 2 was done by revising Scheme 1 by decreasing the power of the lamp used from 110 W to 85 W and by changing the distance among the poles. This was administered due to economic consideration so that the design in Scheme 2 could give recommendations on energy efficiency aspects and lighting comfort.

The results of the simulation also demonstrated that the design in Scheme 2 gives almost similar results to those in Scheme 1. The illustration of 3D illumination distribution shows that the highest lighting distribution was right under the lamp and kept decreasing as it distanced yet still under the national standard of lumination. It was found in Scheme 2 that the illumination value under the national standard occurred under two poles so that it was dark at a certain distance. One of the efforts to cope with this was by using armature to enhance the lighting coverage. The results of simulation in this scheme were quite good on both the right and left sidewalks; all of the required values were on the national standards. In comparison to the simulation results in Scheme 2, the best results were obtained in Design 1, particularly on the aspect of lighting uniformity reflected. Even though the lumination average in Design 1 was above the national standard, it was actually on the normal line; this means that the value is good when the lamp life cycle keeps decreasing. Scheme 1 (Design 1) also showed good uniformity results on both the right and left sidewalks. The results of the complete simulation could also be seen in **Table 5**.

This study found that the PSL technology using LED gave the best solution since all the design schemes meet the national standard (SNI) requirements; the rest of the factors lie in the lamp price and life cycle. The use of LED lamps on the PSL has been proven to repair the quality of the PSL since they have proper lumination and higher energy and economic efficiencies (Stockman & Sharpe, 2006). To be able to come up with the best strategy of redesigning the PSL from conventional lamps to LEDs, the best combination of the design parameters (the lamp height, the distance among the poles, additional lamp units, etc.) need to be selected. All the combinations aim to maximize the lighting uniformity and illumination values based on the standards (Abdullah et al., 2019). Recently, LED technology for PSL was considered the best choice; however, it does not mean that LEDs do not have disadvantages.

It is commonly known that the price of the lamps is still high, therefore, the investment cost is one of the biggest challenges (Eriyadi et al., 2019). Even though LEDs have high potentials for energy efficiency, it has been found that they have such constraints in product maturity, complexity, and uncertainty related to endurance (Duman & Güler, 2019).

Table 5. Average illumination and uniformity in scheme 2.

Design	Average Illumination			Uniformity		
	Left Sidewalk	Roadway	Right Sidewalk	Left Sidewalk	Roadway	Right Sidewalk
Design 1	3.45	8.04	3.05	0.55	0.24	0.53
Design 2	7.28	11.13	1.77	0.17	0.15	0.49
Design 3	4.03	5.10	1.72	0.26	0.14	0.42
National Standard 7391:2008	1–4 lx	3–7 lx	1–4 lx	0.1	0.14	0.1
Conclusion	Meeting the standard	Meeting the standard	Meeting the standard	Meeting the standard	Meeting the standard	Meeting the standard

4. CONCLUSION

This study gave information on the results of designs of PSL on the research site and compared it with the existing condition. Based on the analysis on the research area, the average illumination and lighting uniformity of the PSL went beyond the national standard of the lighting on the category of collector road. Some of the main contributing factors were the un-equal height and distance of the poles as well as the light intensity in each pole. The high illumination could actually be dangerous for road users due to the high amount of light. To be able to have an optimum design, the PSL should also meet the criteria of mesopic vision so that designers should consider such factors as a selection of lamp types, distance among the poles, the pole height, and proper lighting angles affecting the illumination value acquisition on the main road and the sidewalks. It has been proven in this study that the PSL design using a homogeneous luminaire approach with LED lamps gave optimum illumination and lighting uniformity. Further studies on the precise calculation of the relationship of LED selection from various brands towards energy efficiency and the lamp life cycle need to be taken into consideration.

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